# Bipolar Plate-Supported Solid Oxide Fuel Cell

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## Objectives

Develop an improved solid oxide fuel cell (SOFC) for auxiliary power units (APUs).

- Improve mechanical properties (i.e., vibration and shock resistance).
- Improve cell power output by eliminating the contact resistance between cell and interconnect layers.
- Reduce materials costs.
- Develop a low-cost fabrication method.

## Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- D. Fuel Cell Power System Benchmarking
- L. Hydrogen Purification/Carbon Monoxide Cleanup
- M. Fuel Processor System Integration And Efficiency
- O. Stack Material And Manufacturing Cost
- P. Durability
- Q. Electrode Performance

## Approach

- Support a SOFC on a metallic bipolar plate rather than a ceramic layer.
- Reduce the thickness of the anode layer.
- Fabricate cell components using powder metallurgy processing.
- Sinter cell components in one high-temperature processing step.

## Accomplishments

- Achieved sintered laminate of flow fields, bipolar plate, anode, and electrolyte.
- Demonstrated that the bipolar plate-supported SOFC has four times the strength of an anode-supported cell.
- Achieved an open-circuit voltage of 1.14 V (>99% of theoretical value).
- Achieved a single-cell power output >260 $mW/cm^2$.

## Future Directions

- Design and fabricate a short stack (2 cells) to achieve an open-circuit potential that is >90% of the theoretical value on hydrogen/air.

- Test two-cell stack on simulated reformate/air.
- Test startup time, cyclability, and durability.
- Investigate improved materials for the metallic support, anode, and cathode.
- Improve fabrication procedure.
- Collaborate with universities, industry, and other national laboratories.

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## Introduction

Solid oxide fuel cells (SOFCs) are attractive power sources for vehicular auxiliary power applications because they exhibit high power densities and efficiencies, have simplified fuel-reforming requirements, and are fuel-flexible. However, their high operating temperature and the brittle nature of their ceramic cell components have precluded their use. SOFCs have traditionally been operated at ~1000°C because the cell support was a thick doped-zirconia electrolyte layer. Recently, the operating temperature has been lowered to 650-800°C by supporting the cell on a thick ceramic-metal (cermet) anode layer and decreasing the thickness of the electrolyte layer to <20 µm, thus decreasing its resistance. The lower operating temperatures have made SOFCs more viable for transportation applications, allowing better thermal integration with the fuel reformer (operating at ~700°C), the use of metallic flow fields and interconnects, and shorter startup times. However, there are still barriers to the use of SOFCs for these applications, including (1) susceptibility to cracking due to vibration, impact, and thermal shock; (2) contact resistance between the cell components; and (3) high materials and manufacturing costs. The bulk of the materials costs of the anode-supported SOFC lies in the large amount of zirconia in the thick anode support and the cost of expensive alloys in the bipolar plate. The use of a cermet layer to support the cell also makes the cell fragile and susceptible to damage by thermal shock.

## Approach

Argonne researchers are developing a design concept, called the TuffCell, to address the issues facing the use of SOFCs in APU applications. The objective of the Argonne effort is to improve mechanical properties, eliminate contact resistance between the cell and interconnect layers, reduce materials costs, and use low-cost fabrication methods. In the TuffCell concept, the brittle electrolyte and anode layers are co-sintered with the metallic gas flow fields and bipolar plate, forming an integrated repeat unit for stacking. The metallic bipolar plate serves as the cell's support, which increases the mechanical strength and thermal cyclability of the cell. The bulk of the bipolar plate can be made of inexpensive stainless steels, with thin passivating layers at the surfaces exposed to the corrosive fuel and oxidant atmospheres. Materials costs are reduced by using thin layers of electrolyte, anode, and metal alloys on an inexpensive metallic support. In contrast to state-of-the-art SOFC fabrication, which includes several high-temperature sintering steps, this method uses a single-step powder metallurgy process carried out in a programmed atmosphere. Eliminating multiple high-temperature processing steps reduces fabrication costs.

Each component layer of the cell is formed using tape-casting or slurry-coating methods and laminated with other components to form a single stack unit. Laminates containing the electrolyte, anode, fuel flow field, bipolar plate, and air flow field are sintered together in a controlled-atmosphere tube furnace. The cathode is applied and sintered *in situ* during the initial heating of the cell or stack. Figure 1 shows a schematic and photo of the TuffCell stacking unit.

## Results

Several cells varying in thickness have been fabricated using the TuffCell approach. Figure 2 is a scanning electron micrograph of a laminate cross section prior to application of the cathode. This particular laminate consists of a 10-µm electrolyte, 120-300-µm anode, 600-µm flow fields, and a 200-

µm bipolar plate. All of the layers were well bonded, and the electrolyte and bipolar plate were gas-impermeable. The flow fields have 70-80% porosity, and the overall thickness of the laminate is 1.5 mm.

Figure 3 illustrates the improvement in fracture strength of a bipolar plate-supported SOFC over a pre-reduced conventional anode-supported SOFC. The first inflection in the metal-supported SOFC curve marks the fracture of the electrolyte. Further displacement shows the effects of metal ductility. The anode-supported cells fracture in a brittle failure, showing one-quarter of the strength of the bipolar plate-supported SOFC.

Figure 4 shows the improvements in single-cell polarization and power density achieved since the FY 2002 Annual Report. These improvements were realized by improving the microstructure of the nickel-yttria-stabilized zirconia cermet anode to enhance the electrical conductivity (August 2002), and by using a doped-cobaltite cathode with a doped-ceria interlayer (November 2002) rather than the doped-ferrite cathode used in the past.

One of the bipolar plate-supported cells was cycled between room temperature and 800°C at 10°C/min to determine the tolerance of the cells to temperature cycling. Figure 5 shows that there is no degradation in the electrochemical performance of the cell after two temperature cycles (the test was terminated after two cycles).


**Figure 1.** Schematic and photograph of the bipolar plate-supported SOFC stacking unit.

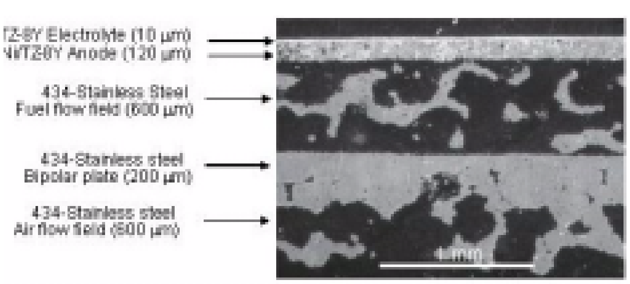


**Figure 2.** Scanning electron micrograph of a sintered bipolar plate-supported SOFC laminate. The laminate contains a dense electrolyte and bipolar plate as well as a porous anode and flow fields. The flow fields are continuously connected below the plane of the figure, achieving a well-bonded monolithic unit.

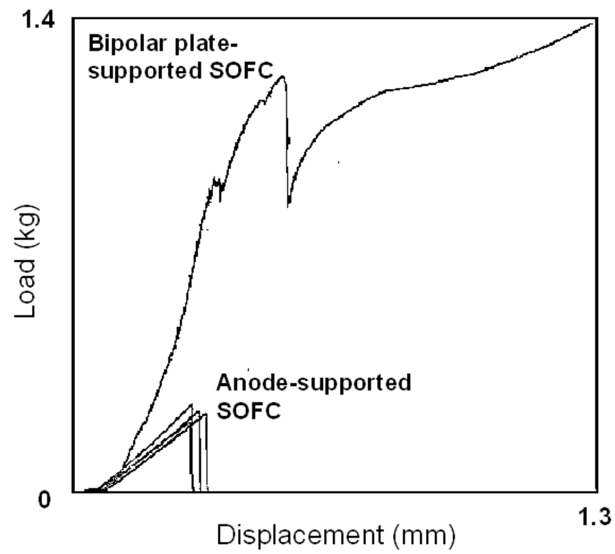


**Figure 3.** Load vs. displacement results of a 4-point bend test comparing the strength of the metal-supported SOFC with the conventional anode-supported SOFC.

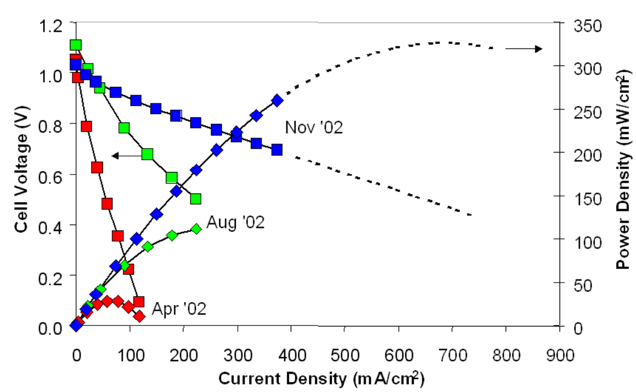


**Figure 4.** Improvement in the single-cell polarization and power density of the bipolar plate-supported SOFC. Cells were tested at 800°C with hydrogen anode gas and oxygen cathode gas.

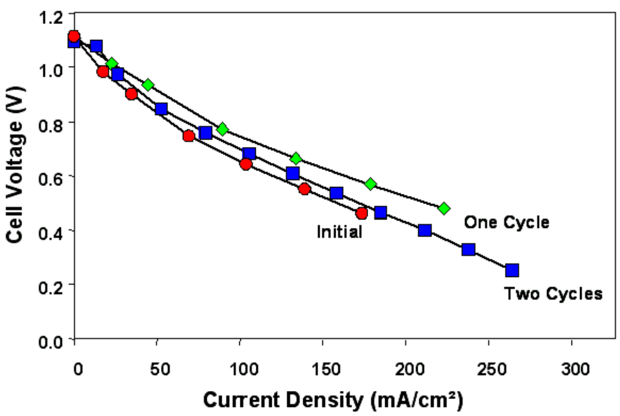


**Figure 5.** Single-cell polarization curves after cycling the cell temperature between 800°C and room temperature at 10°C/min. The cell was tested at 800°C with hydrogen anode gas and air cathode gas.

## Conclusions

A new design and fabrication concept is being developed for the SOFC to address the shortcomings of current designs for portable applications. The design supports the cell on a metallic bipolar plate, and fabrication uses ceramic and powder-metal processing to construct a monolithic unit bonding the flow fields, bipolar plate, anode, and electrolyte in one high-temperature sintering step. Results of four-point bending tests showed that the sintered laminates have four times the load-to-failure capabilities of conventional anode-supported cells. This means that handling and stacking these cells should be easier, and the stacks should be more mechanically robust. Single-cell electrochemical tests at 800°C on hydrogen and air achieved a power density of >250 $mW/cm^2$. With proper refinements to the design and electrode layer compositions, significant improvements in the power density are expected.

Future work will also focus on increasing the individual cell size; building short stacks of cells; testing these stacks using hydrogen and simulated reformate; and determining start-up time, the ability to cycle the temperature, and cell durability. The ultimate goal of this research is to develop rugged, high power density, low-cost stack units made by a commercially viable manufacturing process.

## FY 2003 Publications/Presentations

1. T. A. Cruse, J.-M. Bae, J. D. Carter, R. Kumar, and M. Krumpelt, "A Novel Approach to Making Metallic Interconnects for Planar Solid Oxide Fuel Cells," 2002 Fuel Cell Seminar, Palm Springs, CA (2002).

2. J. D. Carter, J. M. Ralph, J.-M. Bae, T. A. Cruse, C. Rossignol, M. Krumpelt, and R. Kumar, "Improved Materials and Cell Design for Mechanically Robust Solid Oxide Fuel Cells," 2002 Fuel Cell Seminar, Palm Springs, CA (2002).

3. J. D. Carter, T. A. Cruse, J.-M. Bae, J. M. Ralph, D. J. Myers, M. Krumpelt, and R. Kumar, "Bipolar Plate-Supported Solid Oxide Fuel Cells for Auxiliary Power Units," Mater. Res. Soc. Fall 2002 National Meeting, Boston, MA (2002).

4. J. D. Carter, T. A. Cruse, J.-M. Bae, J. M. Ralph, C. Rossignol, D. J. Myers, R. Kumar, and M. Krumpelt, "Application of Cathode Materials to Co-Sintered Metal Supported SOFC," American Ceramic Society 105th Annual Meeting, Nashville, TN (2003).

5. J. D. Carter, T. A. Cruse, J. M. Ralph, and D. J. Myers, "Powder Metallurgy and Solid Oxide Fuel Cells," 2003 International Conference on Powder Metallurgy and Particulate Materials, Las Vegas, NV (2003).

## Special Recognitions & Awards/Patents Issued

1. J. D. Carter, J.-M. Bae, T. Cruse, J. M. Ralph, R. Kumar, and M. Krumpelt, "Solid Oxide Fuel Cell with Improved Mechanical and Electrical Properties" (2002).